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Experimental Testing of PLA Material using Fused Deposition Modeling

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Abstract - *This work particularly targeted to reduce the surface roughness and to increase the surface finish. In Additive Manufacturing (AM), it additionally refers as 3D printing it entails part of production with the aid of using depositing a material in layer with the aid of using layer There is a big selection of various AM technologies, Fused Deposition Modeling (FDM) is one of the maximum common era is used for 3D printing. In this work, a custom designed FDM strategies became advanced for Poly-Lactic Acid (PLA) fabric to enhance surface finish and to reduce the surface roughness. In present work to analyze the various levels of have an impact on of printing temperature, printing speed, layer thickness and ratio of infill density at the mechanical homes of the PLA specimens. The result of printed specimen the surface finish is acquired and surface roughness is reduced.*

Key Words: Fused Deposition Modeling (FDM), Poly-Lactic Acid (PLA), Mechanical properties, 3D printing.

1. INTRODUCTION

Additive manufacturing (AM) technology are one of the maximum promising regions within side the production of additives. Furthermore, they allow the manufacture of a massive variety of prototypes or purposeful additives with complicated geometries, which includes the ones received from a topology optimization manner or generated from a becoming manner in Computer-Aided AM era is a completely huge time period encompassing several techniques which includes Stereolithography (STL) of a photopolymer liquid, Fused Deposition Modeling (FDM) from plastic filaments, Laminated Object Manufacturing from plastic laminations, and Selective Laser Sintering from plastic or steel powders. However, the FDM method is of specific hobby because of its affiliation to computing device 3D printers. FDM forms a 3D geometry through assembling individual layers of extruded thermoplastic filament, which includes acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA), that have melting temperatures low sufficient to be used in soften extrusion in out of doors non-dedicated facilities. FDM is a complicated method with a massive variety of parameters that impact product pleasant and material residences, and the aggregate of those parameters is regularly hard to understand. Printing parameters inclusive of construct orientation, layer thickness, raster angle, raster width, air gap, infill density and pattern, and feed rate, amongst others, have a massive impact at the pleasant and overall performance of FDM published components. Since mechanical properties are vital for practical components, it is really important to look at the impact of method parameters on mechanical overall performance. Thus, similarly research is needed to decide surface roughness and surface finish printer parameters inclusive of construct orientation, layer thickness and feed rate, specifically for the reason that literature at the mechanical residences of components processed by low cost 3D printers is quite scarce. Fused deposition modeling (FDM) is a famous RP generation in large part make use of in industries to construct complicated geometrical green components in short time. The FDM makes use of plastic material within side the shape of maintains cord filament to construct 3D components by melting the plastic filament and depositing at the surface. A plastic filament or metal wire in wounded shape, is unwounded and provides material to feeder within which wire is disentangled up from a loop and supplies material to an extruder which may manage the stream. A worm-drive is provided to push the fibre into the extruder at a managed rate. The extruder is heated the maximum amount as a running temperature at which material starts melt. The resins are heated on top of their glass transition temperature and created them to undergo small orifice stated as hotness spoil in which resins get dissolved & then passes through Nozzle &deposited on printer bed to form the component. Plastic producers all round the international are pressured with environmental and waste management troubles revolving across the inexperienced disposal of the post-commercial plastic waste, which incorporates product rejects, plastic scrap, spruces, and runners. Obviously, plastic waste creates a giant trouble to the producers, as they require to adapt with environmental rules to avoid wasting you pollution. Thus, plastic utilization has drawn interest in conjunction with developing environmental problems additionally to the power of economic blessings by putting in a waste reduction and recycling policy. the answer for those plastic wastes is by recycling and re-using for the downgrade applications.

1.1 Classification of 3D Printer

The term 3D printing encompasses numerous production technology that construct elements layer-by-layer. Each range within side the manner they shape plastic and steel elements and may range in material selection, surface finish, durability, and production speed.

- Stereolithography (SLA)
- Selective Laser Sintering (SLS)

- Fused Deposition Modelling (FDM)
- Digital Light Process (DLP)
- Multi Jet Fusion (MJF)
- PolyJet
- Direct Metal Laser Sintering (DMLS)
- Electron Beam Melting (EBM)

1.1.1 Stereolithography Apparatus (SLA)

Stereolithography (SLA) is the authentic commercial 3D printing process. SLA printers excel at generating elements with excessive ranges of detail, smooth surface finishes, and tight tolerances. The fine surface finishes on SLA elements, now no longer best appearance nice, however can useful resource within side the part's function—checking out the fit of an assembly, for example. It's broadly used within side the scientific enterprise and not unusual place programs consist of anatomical models and micro fluidics.

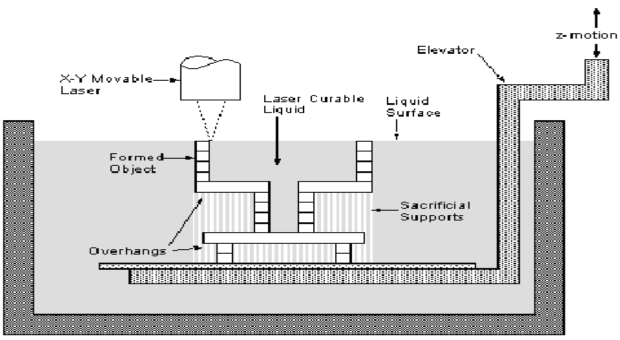

Fig -1: Stereolithography Apparatus

1.1.2 Selective Laser Sintering (SLS)

Selective laser sintering (SLS) melts collectively nylon-primarily based totally powders into solid plastic. Since SLS elements are crafted from actual thermoplastic material, they're durable, appropriate for practical testing, and might guide residing hinges and snap-fits. In assessment to SL, elements are stronger, however have rougher surface finishes. SLS doesn't require guide systems so the complete construct platform may be applied to nest more than one elements right into a single construct—making it appropriate for element portions better than different 3D printing processes. Many SLS elements are used to prototype designs that will one day be injection-moulded. For our SLS printers, we use sPro140 machines advanced by 3D systems.

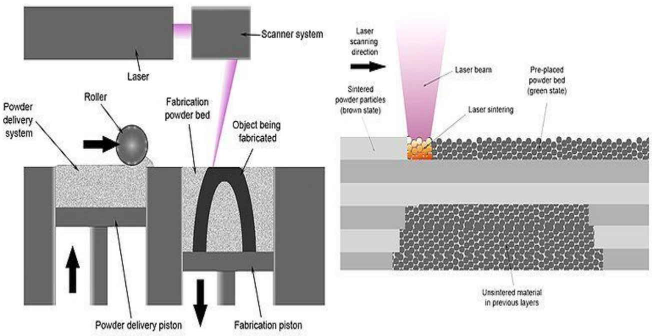

Fig -2: Selective Laser Sintering

1.1.3 Fused Deposition Modeling (FDM)

Fused deposition modeling (FDM) is a common computer 3D printing era for plastic elements. An FDM printer features with the aid of using extruding a plastic filament layer-by-layer onto the construct platform. It's a cost-powerful and quick technique for generating bodily models. There are a few times while FDM may be used for practical trying out however the era is constrained because of elements having incredibly rough surface finishes and lacking strength.

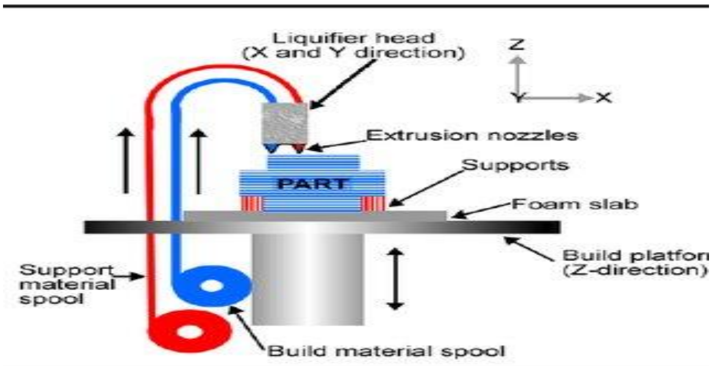

Fig -3: Fused Deposition Modeling

1.1.4 Digital Light Process (DLP)

Digital light processing is just like SLA in that it cures liquid resin the usage of light. The primary difference most of the era is that DLP uses a digital light projector show at the same time as SLA uses a UV laser. This manner DLP 3D printers can image an entire layer of the assemble all at once, resulting in faster assemble speeds. While often used for fast prototyping, the higher throughput of DLP printing makes it suitable for low-volume production runs of plastic parts.

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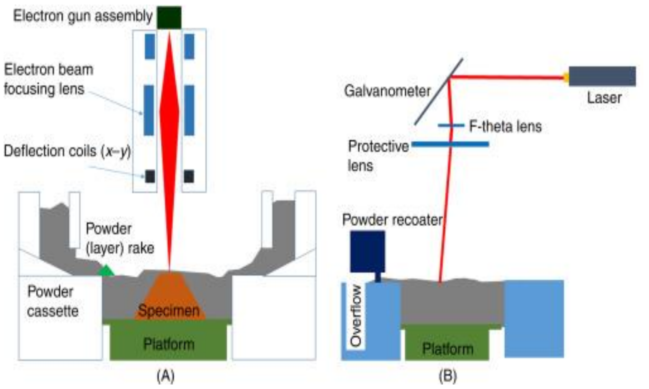

Fig -4: Digital Light Process

1.1.5 Multi Jet Fusion (MJF)

Multi Jet Fusion additionally builds useful elements from nylon powder. Rather than the usage of a laser to sinter the powder, MJF makes use of an inkjet array to use fusing retailers to the bed of nylon powder. Then a heating detail passes over the bed to fuse every layer. This effects in greater constant mechanical properties as compared to SLS in addition to improved surface finish. Another gain of the MJF technique is the improved construct time, which ends up in decrease manufacturing costs.

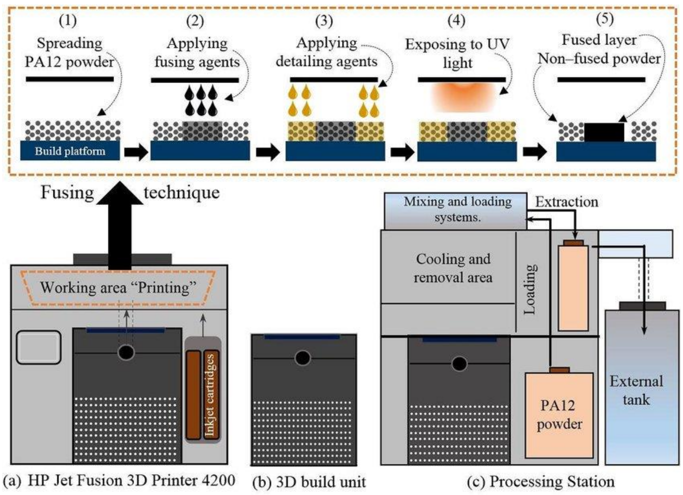

Fig -5: Multi Jet Fusion

1.1.6 Polyjet

PolyJet is another plastic 3D printing process, however there's a twist. It can fabricate elements with multiple properties which include colors and materials. Designers can leverage the era for prototyping elastomeric or overmoulded elements. If your layout is a single, inflexible plastic, we advise sticking with SL or SLS—it's extra economical. But if you're prototyping an overmoulding or silicone rubber layout, PolyJet can prevent from the want to spend money on tooling early within side the improvement cycle. This will let you iterate and validate your layout quicker and prevent money.

1.1.7 Direct Metal Laser Sintering (DMLS)

Metal 3D printing opens up new opportunities for metallic element layout. The procedure we use at Protolabs to 3D print metallic components is direct metallic laser sintering (DMLS). It's frequently used to reduce metallic, multi-element assemblies right into a single thing or light-weight components with inner channels or hollowed out features. DMLS is possible for each prototyping and manufacturing due to the fact that components are as dense as the ones produced with conventional metallic production strategies like machining or casting. Creating metallic additives with complicated geometries additionally makes it appropriate for clinical packages in which a element layout ought to mimic an natural structure.

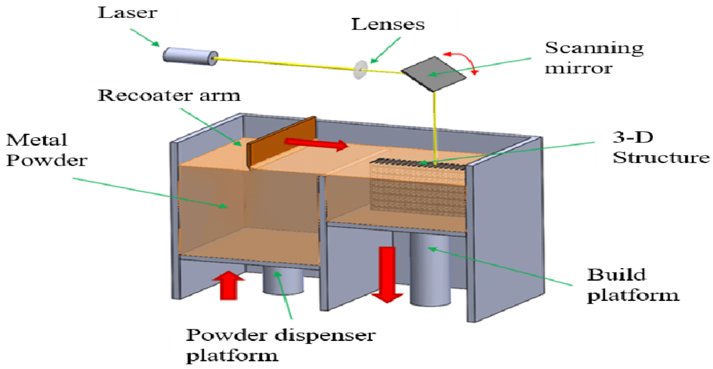

Fig -6: Direct Metal Laser Sintering

1.1.8 Electron Beam Melting (EBM)

Electron beam melting is every other metallic 3D printing era that makes use of an electron beam it really is managed with the aid of using electromagnetic coils to soften the metallic powder. The printing bed is heated up and in vacuum situations for the duration of the build. The temperature that the fabric is heated to is decided with the aid of using the fabric in use.

2. MATERIALS AND METHOD

2.1 Polylactic Acid

PLA has come to be a famous material because of it being economically constituted of renewable resources. In 2010, PLA had the second one maximum intake quantity of any bioplastic of the world, even though it continues to be now no longer a commodity polymer. Its significant utility has been hindered via way of means of several physical and processing shortcomings. PLA is the maximum extensively used plastic filament material in 3D printing. The name "polylactic acid" does now no longer observe IUPAC general nomenclature, and is probably ambiguous or confusing, due to the fact PLA isn't a polyacid (polyelectrolyte), however alternatively polyester.

2.2 FDM Process

The fused deposition modelling (FDM) technology was developed by S. Scott Crump in 1988. Stratasys of Eden Prairie, Minnesota makes Fused Deposition Modelling (FDM) machines for commercialization. FDM is the second most widely used AM technology after the SLA process.

Fused Deposition Modelling (FDM) is a solid based additive manufacturing process which builds parts directly from CAD software. This process uses 3D CAD data and a FDM machine to create 3D objects from solid based AM materials. This procedure may be defined as follows: Initially, filaments of heated thermoplastic are extruded from a nozzle tip that movements withinside the x-y plane. The controlled extrusion head deposits very thin beads of material onto the construct platform to shape the primary layer. After the platform lowers, the extrusion head deposits a second layer upon the primary, and the procedure keeps until the element is absolutely formed. There are multiple types of and names for extrusion techniques, including: FDM (fused deposition modelling), FFF (fused filament fabrication) and sometimes PJP (plastic jet printing).

The Fused Deposition Modelling (FDM) process is simple, comprising of three stages:

- Pre-processing
- Processing
- Post-processing

2.3 Pre-processing

The Fused Deposition Modeling (FDM) system starts with a 3D CAD file of the element. The 3D CAD file is first transformed into STL file, that is a layout that a FDM machine could understood. The facts is then "sliced" horizontally into thin layers of cross sections in z-axis and formatted into FDM construct facts. The FDM machine makes use of the facts to construct the part layer through layer with an extrusion nozzle.

2.4 Processing

The FDM system starts to construct the components from the bottom up through using a computer-controlled print head. A spool of thermoplastic wire is unwound from the coil and is constantly provided to an extrusion nozzle. The 'nozzle heater block' heats up the filament and continues the plastic slightly (0.5°C) above its melting factor. A computer controls the nozzle motion alongside the x- and y-axes. As according to the command from the computer, the nozzle is moved over the desk withinside the required geometry, depositing a thin bead of extruded plastic onto the construct platform. The deposited plastic hardens without delay after being squirted from the nozzle to shape the primary layer.After the primary layer is constructed the platform is decreased by approximately the standard thickness of one layer, and the extrusion nozzle deposits a second layer upon the primary. The deposited plastic hardens without delay and bonds to the layer below.The system preserve till the element is absolutely formed. There is a second extrusion nozzle for the support material. The second nozzle incorporates a support wax to construct the support structure. Some objects have overhangs or undercuts which need to be supported at some stage in the fabrication system by support structures. These are fabricated proper along side the object.The complete machine is contained inside a chamber that's held at a temperature just below the melting factor of the plastic.

2.5 Post-processing

The support structure can without problems be removed. The sacrificial support material is dissolved in a heated sodium hydroxide (NaOH) answer with the help of ultrasonic agitation.

3. EXPERIMENTATION

3.1 Fabrication of 3D Component

3D printing is a producing procedure which builds solid object through layer by layer addition. The layer starts off evolved with single axis (X axis) and pass closer to some other axis (Y axis). After completion of axes it actions closer to Z axis which provides thickness to the item, subsequently offers a stable 3D model. The layout from computer is given as enter to the 3D printer through software program interface.

3.2 Tensile Test

The tensile plate was fabricated with the ASTM standard 638 type 5 (Standard Test Method for Tensile Properties of Plastics). The dimension is 63.5x9.53x3mm. Figure 7 shows the sample used for tensile test. Figure 8 shows the sample after tensile test.

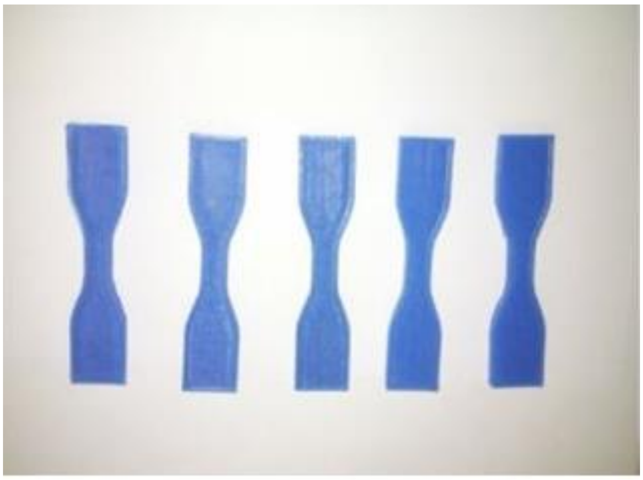

Fig -7: Sample Before Tensile Test

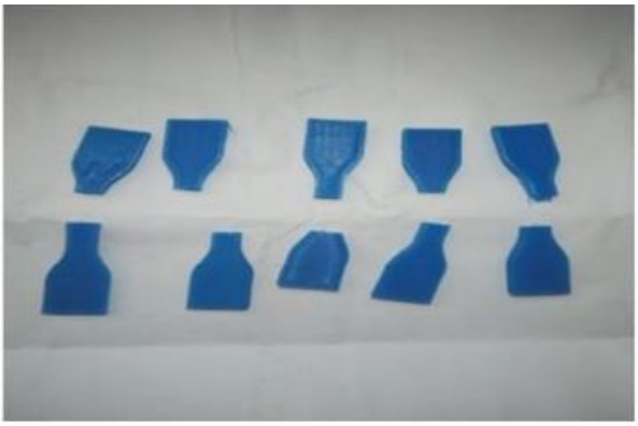

Fig -8: Sample After Tensile Test

3.3 Flexural Strength

The tensile plate become fabricated with the ASTM standard D790 (Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials). The size of the plate is 127x12.7x3mm. Figure 9 shows the flexural test of the 3D printed PLA specimen.

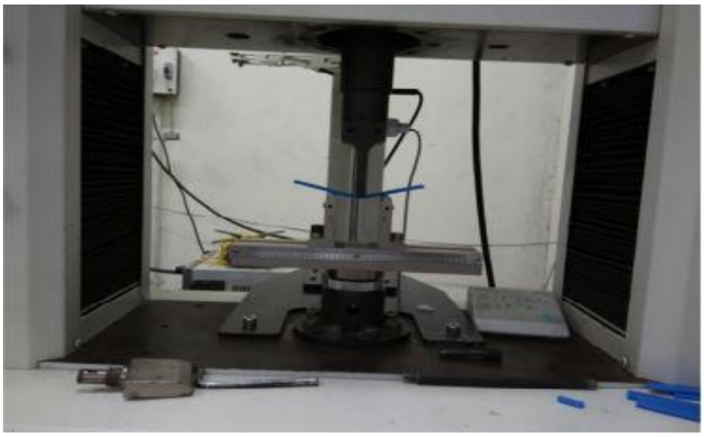

Fig -9: Flexural Strength Test

3.4 Impact Test

Impact test specimen become fabricated with the ASTM standard D256 (Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics). The measurement of the plate is 65x12.7x3mm. Figure 10 shows the 3D printed specimen impact test.

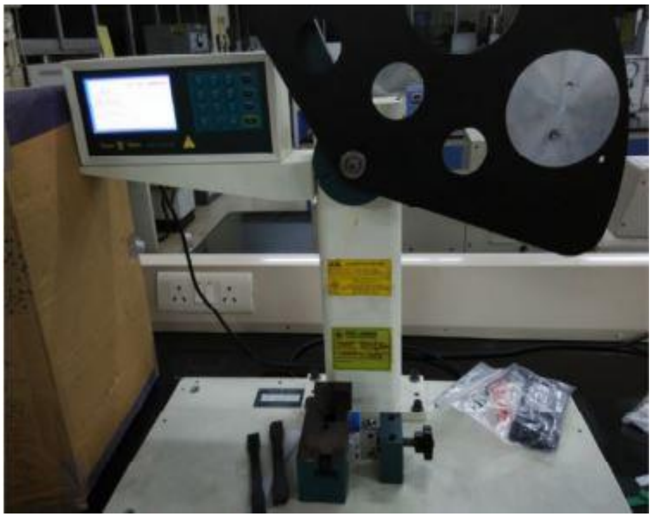

Fig -10: Impact Test

3.5 Surface Roughness Test

Surface roughness is an important parameter while attempting to find out whether or not a surface is appropriate for a sure purpose. Roughness plays an critical position in figuring out how a actual item will have interaction with its environment. In tribology, rough surfaces commonly put on greater fast and feature better friction coefficients than smooth surfaces. Decreasing thoroughness of a surface commonly will increase its production cost. A roughness tester shows the measured roughness depth (Rz) in addition to the mean roughness value (Ra) in micrometers or microns (µm). Measuring the roughness of a surface includes making use of a roughness filter.

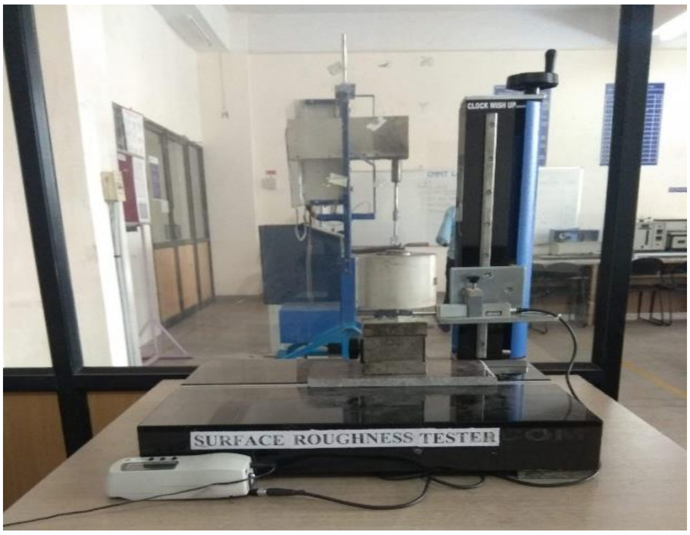

Fig -11: Surface Roughness Test

3.6 Taguchi Method

Taguchi techniques are statistical techniques, or occasionally known as sturdy layout techniques, advanced through Genichi Taguchi to enhance the first-class of synthetic goods, and greater lately additionally implemented to engineering, biotechnology, advertising and advertising. Professional statisticians have welcomed the desires and enhancements added approximately through Taguchi techniques, mainly through Taguchi's improvement of designs for reading variation, however have criticized the inefficiency of a number of Taguchi's proposals

4. RESULTS AND DISCUSSIONS

4.1 Tensile strength of PLA

Table1 shows the tensile test results of the specimen, the average value of tensile strength is **48.66 Mpa.**

Table -1: Tensile strength of PLA

S.No.	Specimen	Tensile Stress at Maximum Load (Mpa)	Modulus (Automatic Young's Mpa)
1	1	47.55	3355.12
2	2	50.23	2734.43
3	3	48.56	3477.23
4	4	49.02	2834.44
5	5	47.95	3133.94

4.2 Impact Test of PLA

Table 2 shows the Impact test value the specimen, the average value of impact strength is **13.7KJ/m².**

Table -2: Impact test values of the samples

S.No.	Specimen	Impact meter strength (J)	Impact strength KJ/m²
1	1	0.6802	14.2183
2	2	0.6108	12.7693
3	3	0.5645	11.8011
4	4	0.8251	17.2486
5	5	0.6070	12.6897

4.3 Flexural Strength of PLA

Table 3 shows the Flexural strength of specimen, the average value of impact strength is **157.28 MPa.**

Table -3: Flexural strength of PLA

S.No.	Specimen	Flexural strength (Mpa)
1	1	158.35
2	2	154.52
3	3	159.07
4	4	158.26
5	5	156.24

5. CONCLUSIONS

This study become carried out to recognize the mechanical properties of 3D printed PLA with the aid of using numerous mechanical tests. 3D printed specimen become fabricated as in line with ASTM standards and examined the usage of popular equipments. PLA may be competitive material to ABS in addition to the fabrication procedure become absolutely eco-friendly due to much less emissions and wastages caused by traditional production procedure. PLA under popular atmospheric conditions indicates weight reduction in suitable manner.

It is observed from the experimental results that the 2nd pattern has were given the very best tensile energy of 50.23 MPa. It corresponds to a layer thickness of 0.1 mm, an extrusion temperature of 200 0C and an infill sample of line structure.

The main effects plot well-known shows the same result. Moreover, the very best cost of tensile power is received at lowest cost of layer thickness (0.1 mm). This is so due to better bonding place among layers. The surface roughness outcomes which offers minimal stage of 0.22 μm which decreases the surface roughness and will increase the surface finish.

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